

LUCENT TECHNOLOGIES, INC.

Precision Mirrors for Advanced Lithography

The personal computer revolution has been powered, in large part, by the development and production of new generations of memory, CPU (central processing unit), and other chips. With each generation, chip feature sizes shrink. However, chip feature size is reaching the limit of what can be produced with current lithography equipment. A new approach to lithography that can operate at shorter wavelengths is essential if the integrated circuit industry is to continue to advance toward more powerful computer chips.

COMPOSITE PERFORMANCE SCORE

(based on a four star rating)

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Advanced Optics to Enable Chip Miniaturization

The ATP project with Lucent Technologies (formerly AT&T) Bell Laboratories significantly improved the accuracy of precision reflective optics — complex multilayer-coated mirrors — that are critical for extreme ultraviolet (EUV) lithography. EUV, or soft x-ray, technology is one of several possible approaches to advanced lithography for manufacturing chips.

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The goal of the project was to discover whether it is possible to create ultrahigh-precision aspherical mirrors that properly reflect EUV wavelengths for use in lithography. This was a high-risk, technically challenging project. ATP cost sharing enabled Lucent to move ahead with a project that otherwise would have been difficult to justify, particularly because so much of the funding would go to collaborators outside the company. Ultimately, the ATP project showed that the technical obstacles were surmountable and that the optics can be manufactured, measured, and aligned.

Characterizing the complex shapes of these mirror surfaces with the high level of precision required for EUV lithography was well beyond the state of the art when the ATP project began. Working with Lucent, Tropel developed a specialized interferometer to measure aspheric surface characteristics, a device that it now uses in other applications. Lucent, in collaboration with Brookhaven and Sandia National Laboratories and the University of Wisconsin,

developed other techniques required to characterize aspheric mirrors. The project also generated increased understanding of multilayer-coated aspherical optics and optics surface finishing, advanced techniques for multilayer coating of mirrors, improved methods for mirror alignment, and new test equipment.

To see whether this new technology would work, Lucent and its collaborators conducted a two-stage, round-robin test. In the first stage, four subcontractors fabricated prototype mirrors using the knowledge created in the project. Then each subcontractor tested mirrors fabricated by each of the four. The mirrors made by Tinsley Laboratories proved to be dramatically better than any of this type ever seen before.

Commercialization Status

When this project began, it was uncertain whether aspheric mirrors with the high level of accuracy required for EUV lithography could be made. And even if they could, it was not clear whether they could be measured with sufficient accuracy to verify that they met the extreme precision demanded by the specifications. Thus, this high-risk project aimed to find out whether the EUV approach to lithography deserved further consideration or whether the mirrors constituted a showstopper technical barrier that could not be surmounted. The project demonstrated that the mirror technical barrier could, indeed, be overcome.

Progress on all the advanced-lithography candidate technologies developed in parallel at industry and

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PROJECT HIGHLIGHTS

Project:

To develop new fabrication, testing, and alignment techniques for making extremely precise aspheric (nonspherical curvature) mirrors to use for lithography in the extreme ultraviolet (EUV) portion of the spectrum. This is one of several approaches being considered for fabricating future generations of computer chips with extremely dense, compact microelectronic circuits.

Duration: 5/15/1991 — 5/14/1994

ATP Number: 90-01-0121

Funding** (in thousands):

ATP	\$2,000	36%
Company	<u>3,525</u>	64%
Total	\$5,525	

Accomplishments:

Lucent and its subcontractors developed dramatically improved techniques for fabricating, testing, and aligning extremely precise aspherical, multilayer-coated mirrors essential to EUV technology, a candidate for future lithography systems. Lithography is a key step in manufacturing integrated circuits. Aspheric mirrors, whose surfaces have nonspherical curvature, are much more difficult to make and measure than mirrors with flat or spherically curved surfaces. They are particularly difficult to make for the ultrashort wavelengths used in this technology. Researchers significantly advanced the state of the art of the physics and metrology for these EUV lithography systems. Signs of the project's success are:

- Lucent contracted with Tropel to develop a new advanced interferometer for measuring the surface properties of aspheric optics. Tropel succeeded and is now using this technology for its own products.

- Tinsley Laboratories, a subcontractor, fabricated mirrors 10 times more precise than any produced before the ATP project. Tinsley has applied the improved methods learned in the project to all its products. In part, because of its improved manufacturing technology, Tinsley doubled its sales between 1991 (the start of the ATP project) and 1996.

- the researchers presented or published more than two dozen papers about precision metrology, aspheric mirror fabrication and lithography systems development.

- three computer chip fabrication companies have agreed to invest \$250 million over three years to continue the research, development and perhaps ultimate commercialization of EUV lithography technology. A critical component of this technology is the multilayer-coated mirrors that were the focus of this ATP project.

Commercialization Status:

Although Lucent has decided to concentrate on another advanced-lithography approach that appears more promising at this time to the company, some technologies developed during the ATP project have already been commercialized, and others may be commercialized in the future. Tinsley's business rose sharply as a result of manufacturing improvements the firm developed to fabricate the aspheric mirrors for this project. Tropel is using the measurement technology resulting from its involvement in the project. And several computer chip manufacturers are incorporating the project results into their lithography R&D. If the EUV approach meets the technical and economic requirements of the chip industry, the ATP-funded technology will be incorporated into equipment used to produce computer chips in the first decade of the twenty-first century.

Outlook:

The high-quality Tinsley mirrors, fabricated and tested with methods discovered during the ATP project, are a key component of the EUV approach to new generations of lithography equipment. If this approach proves to be technically and commercially viable, it will enable a new generation of chip-making equipment that will generate benefits for chip manufacturers, as well as users of computers, communications equipment, and other electronic devices containing the new chips.

Composite Performance Score: **

Company:

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Informal Collaborators: Sandia, Brookhaven and Lawrence Livermore National Laboratories and NIST.

** As of December 9, 1997, large single applicant firms are required to pay 60% of all ATP project costs. Prior to this date, single applicant firms, regardless of size, were required to pay indirect costs.

government laboratories during the early 1990s. As data accumulated, Lucent decided in 1995-1996 (well after the ATP project ended) to reduce its effort in EUV lithography and focus its attention on another option — scattering with angular limitation projection electron-beam lithography (SCALPEL) — which it deemed more promising. Lucent still monitors developments in all areas of advanced lithography, and substantial work on EUV lithography continues elsewhere, particularly at Lawrence Livermore and Sandia National Laboratories.

In 1996 Intel, AMD, and Motorola formed the Extreme Ultraviolet Limited Liability Company to pursue EUV lithography. In September 1997, this consortium and the Virtual National Laboratory (a collaboration of Lawrence Berkeley, Lawrence Livermore, and Sandia National Laboratories) agreed to collaborate on the development of EUV lithography. EUV systems would draw on the optics work from the ATP project and related technology developed at the national laboratories. The three chip makers intend to invest

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about \$250 million over three years in the collaboration to determine whether the technology is commercially viable and, if it is, to pursue commercialization via lithography equipment manufacturers.

It is too early to tell whether the EUV or one of the other approaches to lithography will ultimately win in the marketplace. But it is clear that the ATP project has helped the industry understand the technical barriers to one major candidate technology and how to overcome them. The ATP project results are important to this effort because the kind of aspheric mirrors that Tinsley learned to make under contract to Lucent will be a critical component of the EUV lithography equipment.

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ATP-Project Benefits Could Be Huge

Benefits have already started accruing to Tinsley, which produced the best aspheric mirrors, and to its customers who use the mirrors. Tinsley attributes much of its recent success to the ATP project, because the company was able to apply the improved manufacturing processes — developed to supply aspheric optics for the project — to all its products. Tinsley's sales have approximately doubled since the ATP project. Furthermore, in just 27 months the value of Tinsley's stock increased 600 percent, indicating the value the market places on the company's enhanced capabilities. Tropel and its customers are also continuing to reap benefits from the interferometer.

If EUV lithography equipment incorporating the new aspheric mirror technology becomes the technology of choice for the next generation of chip-making equipment, the benefits of the ATP project would be far broader. The new technology would have a huge economic impact on the semiconductor industry and generate spillover benefits to companies that use the improved computer chips in a wide variety of products, as well as to consumers who use these products.

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Even if another lithography approach becomes the technology of choice, benefits to companies like Tinsley and Tropel and to their customers will continue to accrue. This project illustrates the important fact that a lack of immediate commercialization after an ATP project ends does not mean that the new technology will not eventually be commercialized and yield large benefits.

Information gathered in this project helped Lucent better understand the technical issues related to EUV lithography. Publication of numerous technical papers resulting from the project has advanced the state of the art for everyone in this technical community. And although Lucent later decided to pursue an alternative lithography approach, other companies have incorporated the ATP-funded technology into research and development work that could lead to systems that are commercialized in the future.